Transportation Synthesis Report

Nina McLawhorn
Research Administrator
Wisconsin Department of Transportation
608-266-3199
nina.mclawhorn@dot.state.wi.us

Construction Vibration and Historic Buildings

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Transportation Synthesis Reports (TSRs) are brief summaries of currently available information on topics of interest to WisDOT technical staff in highway development, construction and operations. Online and print sources include NCHRP and other TRB programs, AASHTO, the research and practices of other state DOTs, and related academic and industry research.

REQUEST FOR REPORT

Wisconsin's historic buildings are treasures to state residents and visitors alike. When highway construction activities produce perceptible vibrations, people entrusted with the care and protection of nearby historic structures occasionally become alarmed – and may take steps to halt the projects. They fear the vibrations may cause damage to the historic buildings, although little evidence exists to support this concern.

WisDOT follows Wisconsin Department of Commerce regulations for vibration monitoring and assessment of impacts when required. See Wisconsin Administrative Code, Chapter COMM 7.64, at http://folio.legis.state.wi.us/cgi-bin/om_isapi.dll?clientID=90956&infobase=code.nfo&j5=COMM%207.64&jump=COMM%207.64&softpage=Browse_Frame_Pg. However, when concerns are raised specifically about potential damage to historic buildings, this falls outside the scope of DOC regulations. In these cases, transportation professionals currently have little choice but to respond to preservationists' concerns on a project-by-project basis, resulting in duplicated effort and wasted time and money. To remedy this, WisDOT's chief historian asked the RD&T Program to gather current research and practice related to construction vibration as a first step in preparing an objective information piece that can be made available to the public in advance of construction projects near historical buildings.

SUMMARY

Our exploration of construction vibration and its potential effects on historic buildings took us to state DOT Web sites, officials within several state DOTs, the Federal Highway Administration, a leading expert at a major research university, and several consulting firms.

We begin this report with definitions of relevant terms (see **Background),** taken largely from work by the now-defunct U.S. Bureau of Mines. That agency's approaches to measuring blast-induced vibrations are still frequently applied to measurement of construction-related vibrations.

The debate over whether construction activities damage historic buildings is, in many cases, as old as the buildings themselves. And while significant advances have occurred in pile driving, pavement breaking, and other techniques over the past century, human nature remains basically unchanged. When a vibration rattles teeth and assaults the senses, people assume the building they're in feels the disturbance as much as they do. And after the vibrations subside, they often look around and "observe" damage that they are certain didn't exist before.

Research on human response to vibrations suggests that people have an annoyance threshold far lower than any building's susceptibility to damage, even under the worst of circumstances. And research has also shown that the

effect of weather on structures is far more significant than construction vibration. We highlight findings of two leading investigators on these topics under **Recent Research.**

State DOTs familiar with the backlash that can accompany highway construction projects – even before a single vibration shakes the ground – have learned to show extra sensitivity to public perceptions. We include at **State DOT Approaches** several recommended practices to minimize public misunderstanding, resistance and litigation.

We include a number of **Additional Resources** from FHWA, TRB, universities and the private sector, although we were surprised that we found no public-information pamphlets or general guidance documents on this topic.

The bottom line: little evidence exists that construction vibrations pose a significant risk of damage to historic buildings, but transportation professionals need to convince people of that fact or remain vulnerable to their claims, no matter how specious. Information presented in simple terms that a layperson can understand is part of the education process, along with documentation of a vulnerable building's condition – before, during, and after construction.

BACKGROUND

Historic buildings

What constitutes a "historic" property? Section 800.4 of the National Historic Preservation Act (Section 106) lists criteria by which structures and other sites may be considered eligible for federal protection from "adverse effects" of construction or other activities. See http://www.achp.gov/regs.html#800.5. The Wisconsin Historical Society (www.wisconsinhistory.org/) is a local resource. See the Wisconsin Archaeological and Historic Resource Database (www.wisconsinhistory.org/histbuild/wisahrd/index.html) to search for protected sites.

Vibrations

The now-defunct U.S. Bureau of Mines recommended a "safe blasting limit" of 50 mm/s (2 in/sec) peak particle velocity (ppv). See "Structure Response and Damage Produced by Ground Vibration from Surface Mine Blasting," U.S. Department of the Interior, Bureau of Mines, Report of Investigations 8507, 1980. This limit is frequently applied to construction vibrations and still widely viewed by many engineers as stringent enough to prevent damage to most surrounding structures regardless of age or fragility. But states that have published their own limits for "safe" vibration have tended to start from the Bureau of Mines guideline and halve, or even decimate, it "just to be safe," particularly where historic buildings are involved. (Dowding comments on the faulty logic behind this on page xvi of his book, *Construction Vibrations*, cited below.) For example, the California Department of Transportation (Caltrans) has set an "architectural damage risk level" for continuous vibrations (peak vertical particle velocity of 5 mm/sec or 0.2 in/sec) that is one tenth of the maximum "safe" level of 50 mm/sec (2 in/sec) for single events. For ruins and ancient monuments, as well as historical buildings or structures in poor condition, Caltrans recommends an upper limit of 2.0 mm/s (0.08 in/sec) for continuous vibrations.

Damage

In almost every instance, the damage allegedly caused by construction activities is superficial or "architectural"—meaning cosmetic hairline cracks, primarily in plaster. Catastrophic, or even severe, damage to buildings from vibrations or blasting is virtually unheard of. A considerable amount of research has been done to correlate vibrations from single events such as dynamite blasts with architectural and structural damage. The Bureau of Mines conducted tests in the early 1980s to compare the effects of blasting (and even intentional shaking) on a house against the cumulative effects of weather. See RI 8896, 1984, "Effects of Repeated Blasting on a Wood-Frame House." See abstract at http://outside.cdc.gov:8000/BASIS/ciss/pubs/pubs/DDW?W%3DTITLE+PH+IS+%27frame%27%26M%3D3%26K%3D3998%26R%3DY%26U%3D1.

RECENT RESEARCH

The Effects of Vibrations and Environmental Forces: A Guide for the Investigation of Structures, Lewis L. Oriard, International Society of Explosives Engineers, 1999. Now available in the WisDOT Library.

This book is conceptual in approach and conversational in style, and thus will be useful to a wide range of readers. Though its primary emphasis is the comparison between static environmental forces and construction-related vibrations, perhaps its greatest benefit is its practical recommendations for another sort of damage control – bad press and negative public sentiment. See the introduction and chapter 11, particularly. Throughout the book, Oriard offers helpful suggestions based on his investigations and experience. For example:

- Among the common types of cracks that cannot be caused by vibration are those vertical cracks that often occur in chimneys when they are subjected to high heat stresses. (p. 52)
- Developing an appropriate field procedure before starting a construction project can help contractors and others balance practical considerations against public relations needs and documentation. (p. 211)
- A better understanding of threshold damage will help users better evaluate research reports and place research findings in the context of regulations. (p. 211)
- Make sure the proper questions are being asked in damage investigations. (See the list on p. 272.)

Construction Vibrations, Charles Dowding, Prentice Hall, 1996. Now available in the WisDOT Library.
A civil engineering professor at Northwestern University, Charles Dowding is considered a leading expert on the subject of construction vibrations. In addition to his academic experience, he has participated in many major highway construction projects, including several that raised the ire of preservationists and led to severe and costly delays (most notably, the I-35 project in Duluth, Minn., in the 1980s).

Dowding has condensed more than two decades of research and consulting experience into his book *Construction Vibrations*. Drawing from his previous book, *Blast Vibration Monitoring and Control,* this comprehensive publication goes beyond earthquake analysis, mine and construction blasting, and military blast protection to encompass the larger field of construction vibrations.

In this fairly technical work Dowding presents extensive data on the overriding effects of weather on structures (see chapter 13). From the first moment of construction, a building and its components are under siege from thermal effects of sun and artificial heating, water and frost, chemical changes in building materials, organic action of bacteria on soil, and settlement and other changes in the soil resulting from shifts in the water table. Here are some of his observations/conclusions:

- Homes expand and contract preferentially along existing weaknesses (cracks). Seasonal expansion and contraction along these cracks will return patched and repainted surfaces to the original cracked state within several years. (p. 183)
- Cracks from environmental stresses occur naturally over a period of time. That's why pre-construction inspection is important *immediately* before a specific event. (P. 183)
- Approximately once a week a house is naturally subjected by changes in the weather to deformations equal to those produced by the maximum ground motion permitted by blasting. (p. 201)
- Existing thresholds for avoiding adverse human response do not adequately account for the typical range of construction vibrations, since they are based largely on continuous motion test results. (p. 375)

"Measure the Crack Instead of Construction Vibrations," Charles Dowding, available online at www.iti.northwestern.edu/acm/articles/geostrata.html.
This is a concise, readable and informative paper that may provide good material for a WisDOT information piece. The new crack displacement techniques described in the paper allow homeowners or building caretakers to see the effects of environmental phenomena with their own eyes, and also see that vibration-induced cracking is minor by comparison. Excerpts from the paper:

- "Many people incorrectly believe that construction vibration causes damage to their homes or buildings…The fact is, cosmetic cracking from construction vibrations has not been observed below peak particle velocities of 0.8 in/sec… Motions that people truly believe are harmful usually turn out to be below the government standard."
- "Relatively inexpensive systems to monitor both crack response and ground motion have been developed that involve the manual downloading of data on a periodic basis. These systems can be combined with telecommunications for display on the Internet. The public can then access the data, which increases their confidence in the information."
- "Approximately once a week this house is naturally subjected by changes in the weather to deformations that produce crack displacements equal to those produced by ground motions of at least 0.5 in/sec. Every week, season by season, houses deform significantly more than they would from a typical blast."

Contact Dowding at his Web site, http://www.civil.northwestern.edu/people/dowding.html, or download his free "NUVIB" analytical software, which allows digitization, analysis, display, and plotting of time histories generated by construction vibrations.

"Vibrations Induced by Construction Traffic: A Historic Case Study," a presentation at the Geophysics 2002 Conference, April 15-19, 2002, J.T. Henwood, K.Y. Haramy. Available on CD-ROM in the WisDOT Library. This paper compares and condenses current regulatory guidelines for construction vibrations, including standards from Germany and Switzerland, and includes a case study of a historic district in Georgetown, Colorado. Test procedures, data analysis, interpretation, limitations, and results are summarized.

A few findings and observations from this paper:

- "For years, many regulatory agencies throughout the world have attempted to establish limiting vibration criteria. Various state and federal agencies have adopted empirical vibration limits, based on blasting research, to serve as a blanket guideline for all construction induced vibrations. Due to either the natural frequency of the ground motion or natural period of the structure, these limits are commonly used where they do not apply." (p. 3)

- In the early 1990s it became necessary for the FHWA Central Federal Lands Highway Division to haul pavement construction materials through the city of Georgetown, Colorado along a route with numerous 19^{th} century historic structures. FHWA conducted a noise and vibration study to monitor effects on the structures.
    - "Vibration levels experienced during periods of construction traffic were generally lower than those vibrations commonly generated in this area. Only one record during truck traffic was higher than the 3 mm/s (0.12 in/s) limit established in the Swiss standard for buildings of historical significance. Further analysis indicates that the record is within acceptable limits because of the associated high frequency (170.6 Hz)." (p. 7)
    - "In all cases, vibration levels appeared well below the established Swiss criteria. It was then the recommendation of the FHWA to the city of Georgetown that future construction traffic, to the level that was studied, would not produce structurally damaging ground vibrations." (p. 8)

- "Several forms of vibration criteria have been presented, as well as the results of an investigation on vibrations induced by construction traffic. The reader is cautioned that the measurement results presented are applicable only to the site at which the measurements were made. The vibration performance of various equipment and geologic site conditions should be evaluated on a site-by-site basis." (p. 8)

STATE DOT APPROACHES

California

In its technical advisory from 2002 called "Transportation Related Earthborne Vibrations," Caltrans spells out its vibration limits (described above under **Background**) and offers as a best practice the collecting of extensive background information, clearly stating the purpose of each project, taking scrupulous measurements, and otherwise documenting everything possible. See
http://www.dot.ca.gov/hq/env/noise/pub/TRANSPORTATION%20RELATED%20EARTHBORNE%20VIBRATIONS.pdf.

Another California project with historic buildings at stake was the 1998 retrofitting of the east span of the San Francisco Bay Bridge to meet current seismic safety standards. It involved monitoring historic properties on Yerba Buena Island (YBI), the mid-point anchorage for the bridge, even though all vibration levels were expected to be well below the architectural damage risk level. See the Department of the Navy's comments on the Environmental Impact Statement for the Project at
http://216.239.39.100/search?q=cache:md2Q9vcRBg4C:www.dot.ca.gov/dist4/sfobb/10-Navy_text.doc+%22vibration+damage%22+fhwa&hl=en&ie=UTF-8

> "Comment 38 – "Normal" project construction activities do not generate substantial levels of vibration, but in rare circumstances can damage structures. Pile driving occurring within 30 meters (100 feet) can cause architectural and structural damage to some buildings, especially unreinforced or older buildings. Since all buildings on YBI would be more than 30 meters (100 feet) away from construction activities that would generate vibration, it is expected that vibration levels experienced at buildings would be well below the architectural damage risk level. While no damage is expected, historic properties on YBI would be monitored for vibration damage."

Florida
In Florida, the "Construction Impacts" section of Rev. 1-12-00 PART 2, CHAPTER 30 doesn't talk about historic buildings but does suggest language for posting in communities when work is about to start. See http://www11.myflorida.com/emo/pubs/pdeman/pt2ch30.pdf.

Nebraska
In Nebraska, "Appendix C: Vibration Technical Memorandum Antelope Valley Draft Environmental Impact Statement" describes a proposed roadway and stormwater management project that might affect a sensitive, though not historic, building—the Beadle Center at the University of Nebraska, which houses sensitive microscopes. The appendix suggests that sonic pile drivers may provide a substantial reduction of vibration levels compared to impact-type drivers near the Beadle Center. See http://www.ci.lincoln.ne.us/city/pworks/antelope/pdf/bpdeis.pdf.

Michigan
Another Environmental Impact Statement, this time from the Michigan DOT, recommends "special consideration" be given to historic structures in the event of vibration impacts. It also recommends pre-construction surveys of basements. See the draft document, especially section 7.15, at http://www.mdot.state.mi.us/i94rehab/deis_docs/7Mitigation011701.pdf.

Indiana and Kentucky
This 2003 Programmatic Draft Memorandum of Agreement details how two states joined forces to tackle vibration damage mitigation during a large-scale public works project: http://www.kyinbridges.com/pmoa.pdf. Attachment D lists "historic properties determined to have an adverse effect for the project" but doesn't specify what those effects might be. It does stipulate that agencies in both states exercise special care to avoid damage to properties protected under Stipulation III of the agreement, including pre- and post-construction surveys and construction monitoring.

Other state DOT historic structures contacts
James Andrews, Caltrans, at jim_andrews@dot.ca.gov.
Harrison Marshall, NC DOT, at hmarshall@dot.state.nc.us.

ADDITIONAL RESOURCES
FHWA's 1996 "Community Impact Assessment: A Quick Reference for Transportation" is a useful document for transportation professionals dealing with "hot" public issues. www.fhwa.dot.gov/environment/nepa/cia.htm

The Transportation Research Board's Committee A1F04 on Transportation-Related Noise and Vibration (see the link under "Committees" at www.trb.org) keeps tabs on research related to this subject, though it seems more focused on noise. We talked to committee chair Ken Polcak and staff person Kimberly Fisher for this report.

Northwestern University's Infrastructure Technology Institute, in which Charles Dowding plays an active role, has extensive resources for transportation professionals, in addition to Dowding's article on measuring cracks, discussed above. http://www.iti.northwestern.edu/

The Institute for Research in Construction at the National Research Council of Canada has a number of studies on construction-induced vibration as well as vibration tests of various building types. http://irc.nrc-cnrc.gc.ca/facilities.html.

"Noise and Vibration During Construction" on the Web site of Harris Miller Miller & Hanson Inc., a leading noise and vibration control company focusing on the transportation field. The report contains a description of measurement techniques and refers to historic buildings in section 12.2 on page 8. http://www.hmmh.com/rail/ch12.pdf.

The Acoustics Laboratory at the Volpe National Transportation Systems Center http://www.volpe.dot.gov/acoustics/.

Ron Eshleman, director, Vibration Institute, at vibinst@anet-chi.com.

"Assessing the Effect of Vibration on Historic Buildings" by Walter Sedovic
The Association for Preservation Technology Bulletin, Vol. XVI No. 3 & 4, 1984
"Effect of Vibrations on Historic Buildings: An Overview" by J.H. Rainer
The Association for Preservation Technology Bulletin, Vol. XIV No. 1, 1982